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(71) Applicant
Revlon Inc .

(Incorporated in USA-Delaware)

767 Fifth Avenue, New York, New York 10153, United States of America

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(72) Inventors
Jack A. Ekchian
Robert W. Hoffman
Leon Ekchian
Kaigham J. Gabriel

(74) Agent and/or Address for Service
Withers & Rogers, 4 Dyer's Buildings, Holborn, London EC1N 2JT

(54) Item identification transponder tag

(57) An item identification tag for a stock control system comprises a printed circuit transponder with spiral arms 34, 36, 38, 40, 42 and 44 of length such that the tag acts as a resonant transponder tuned to predetermined frequencies. The arms are made of etched copper foil mounted on a flexible nonconductive substrate 46. Pairs of arms correspond to frequencies of F1, F2 and F3 arranged that upon excitation of frequencies F1 and F2 the tag emits the frequency F3 which is the sum of F1 and F2. Groups of stock items in a stocking area are each assigned specific frequencies, and each item in a group has associated with it a tag tuned to the frequencies assigned to that group. To perform an inventory, a mobile transceiver repeatedly sweeps through a set of transmit/receive frequencies to interrogate the groups of items thereby to collect data from which a total number of items for each group can be computed.
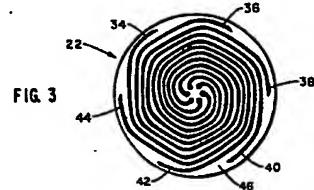
FIG. 3

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FIG. 1

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FIG. 2

$)F_1)$ & $)F_2 \rightarrow$ $\leftarrow F_3$ 20
22

ANTENNA
18

MICROCOMPUTER
16

14

TRANSCEIVER

888 888 24
DISPLAY

PRINTER 28

KEYBOARD 26

FIG. 3

36
34
22
38
44
42 40
46

FIG. 4

RESONANT A $F_3 = F_1 + F_2$

NON-LINEAR
MUTUAL
COUPLING
CAPACITANCE

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FIG. 5

PHASE LOCKED TRANSCEIVER

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5 KHz REFERENCE

60 φ COMPARATOR

62 CHARGE PUMP

64 φ COMPENSATION

66 AMP

68 VCO

70

72

74 BUFFER

76 ÷ 2

78 ÷ N

80 INTERFACE CHIP

MICROCOMPUTER BUS

PHASE LOCKED LOOP (PLL)
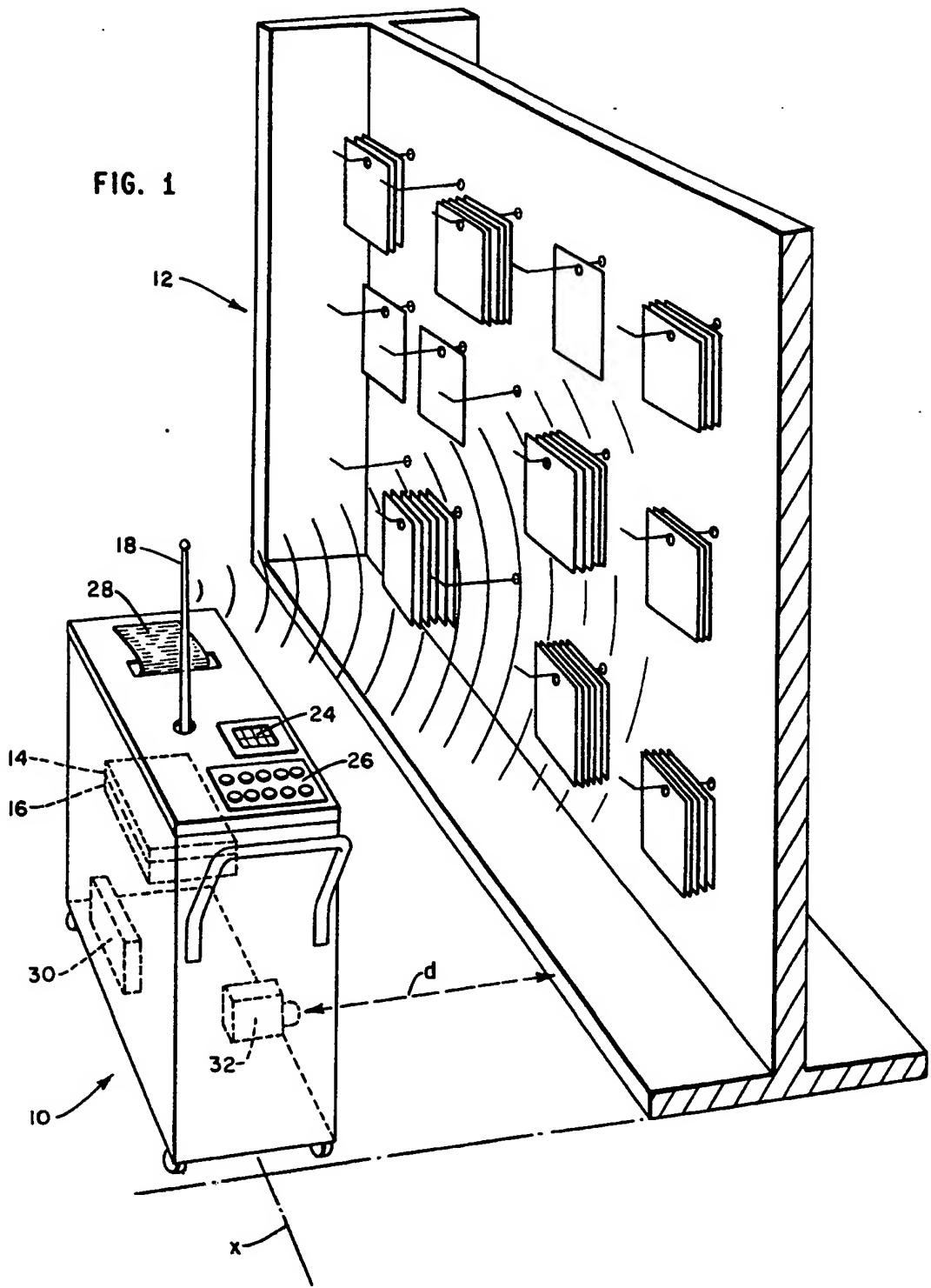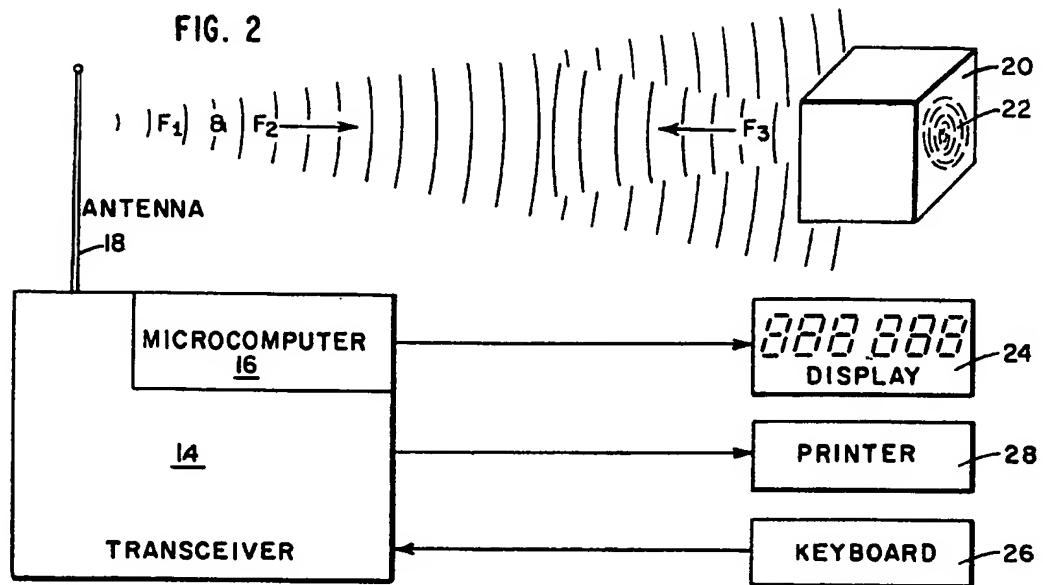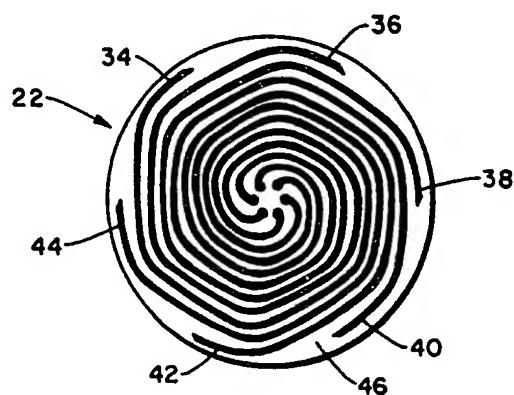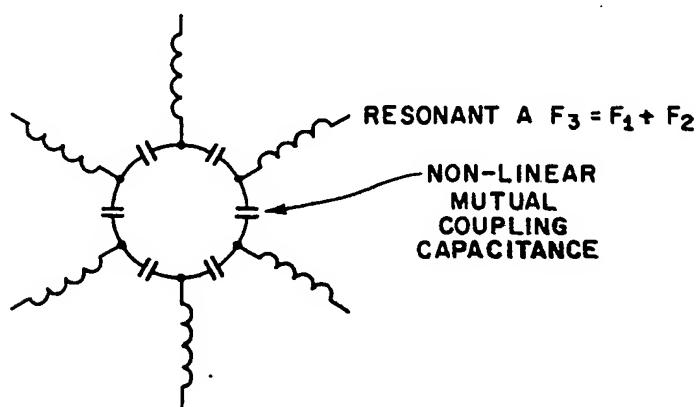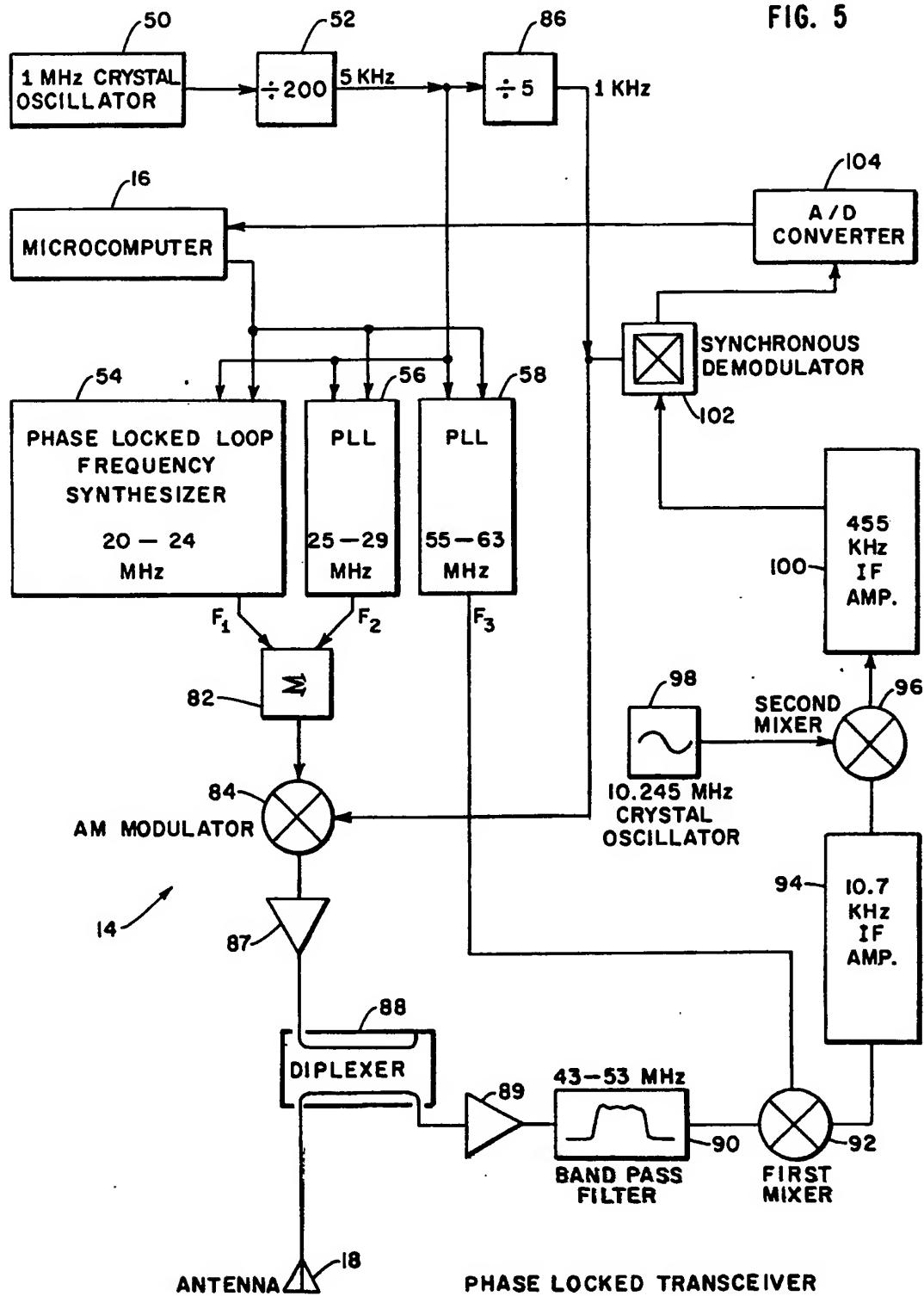
FIG. 6
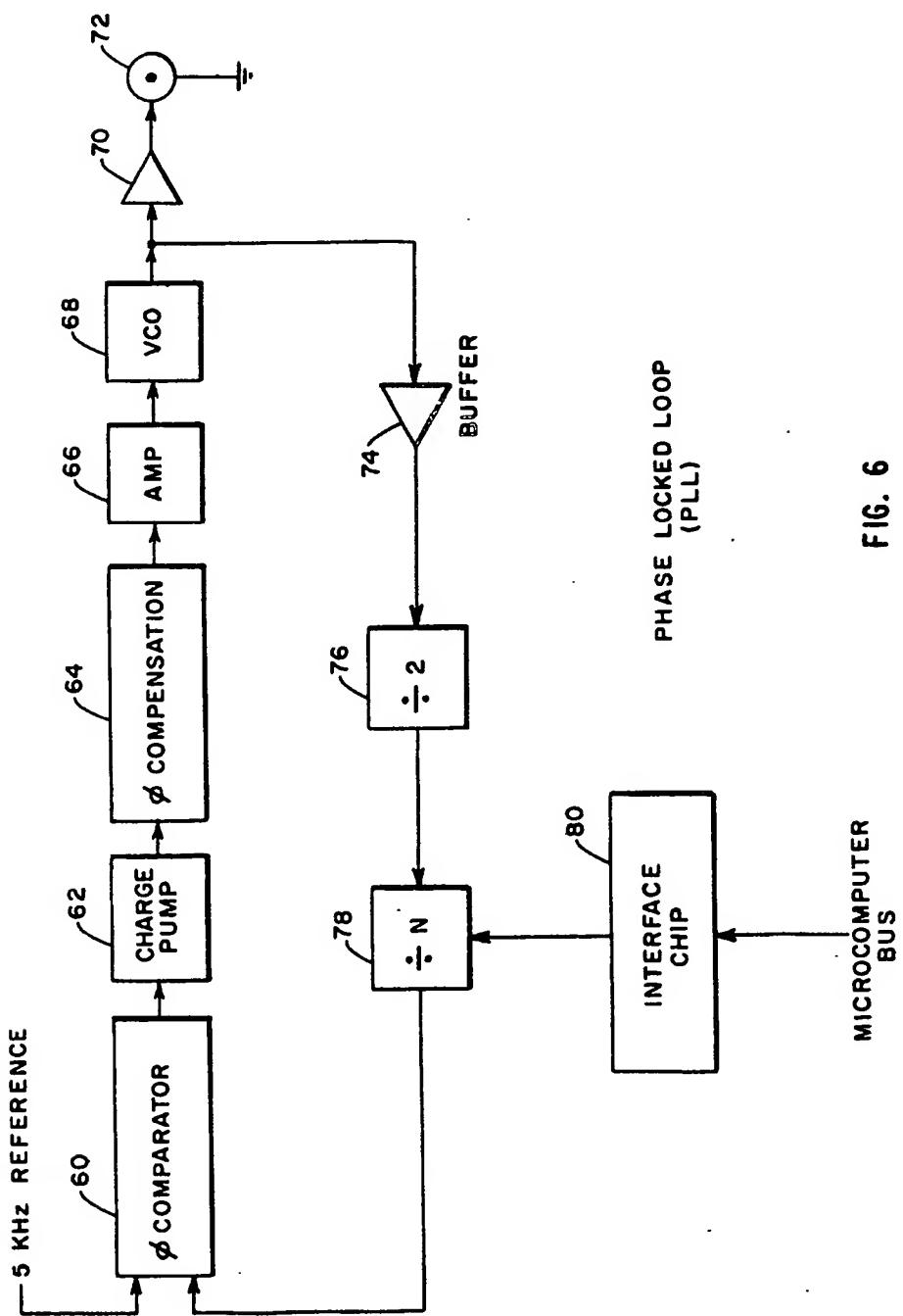
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FIG. 7

FIG. 8

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FIG. 9

$\underline{12}$

22

Δx

y

x

FIG. 10

8

6

4

2

(x)

Δx

x

FIG. 11

$h(x)$

x

FIG. 12

$h(x,y)$

x

y

FIG. 13

$E(x)$

x

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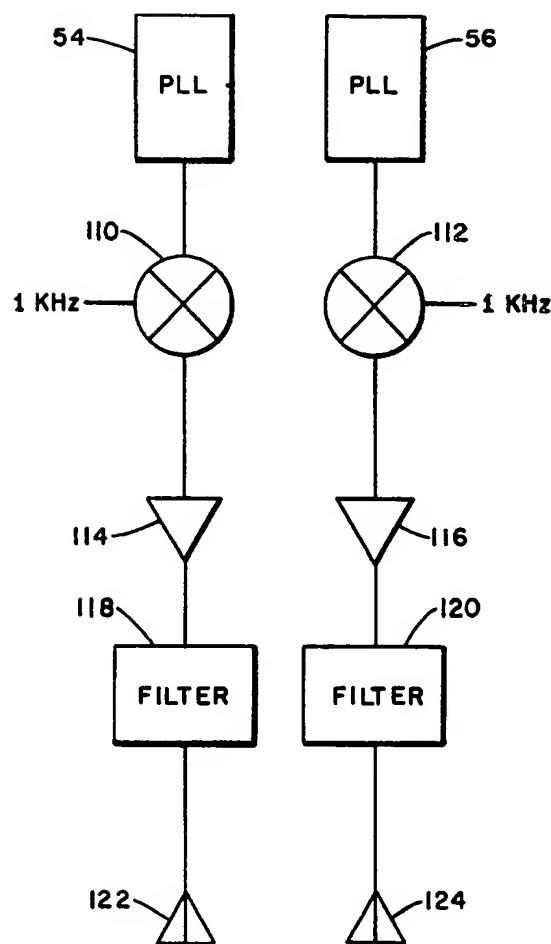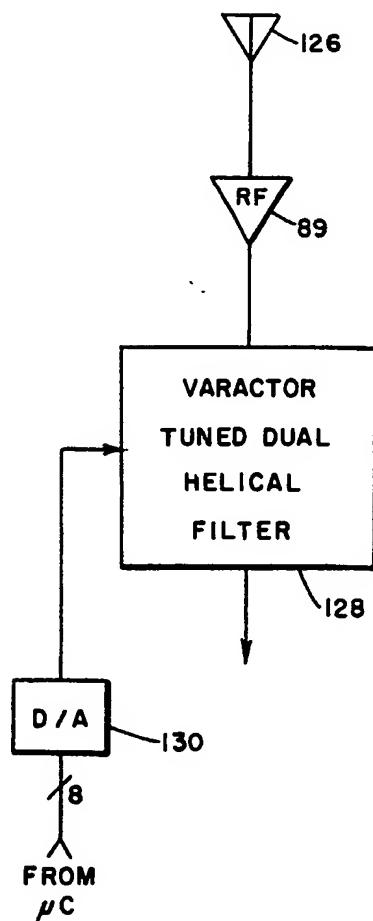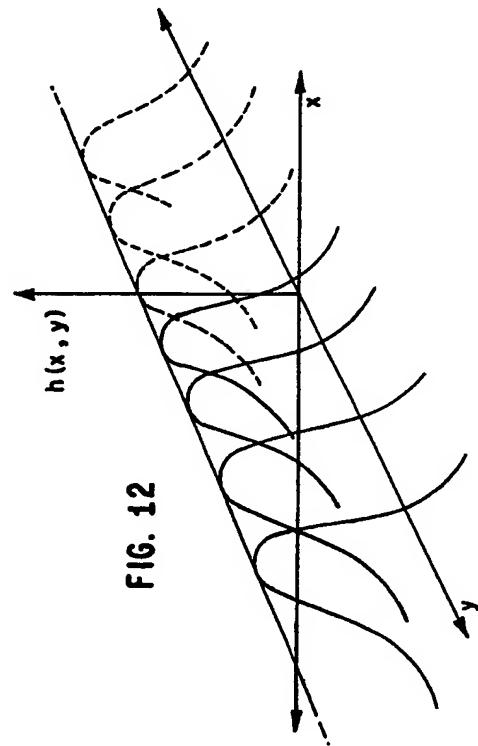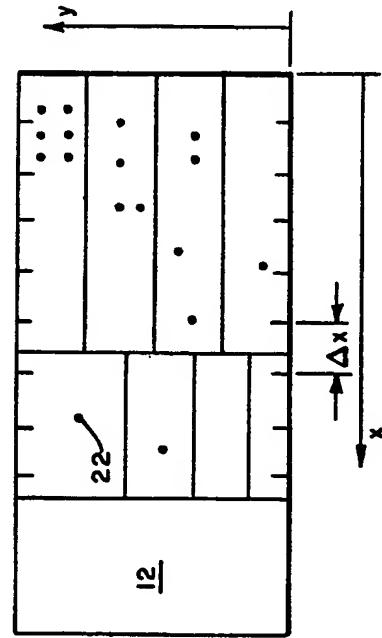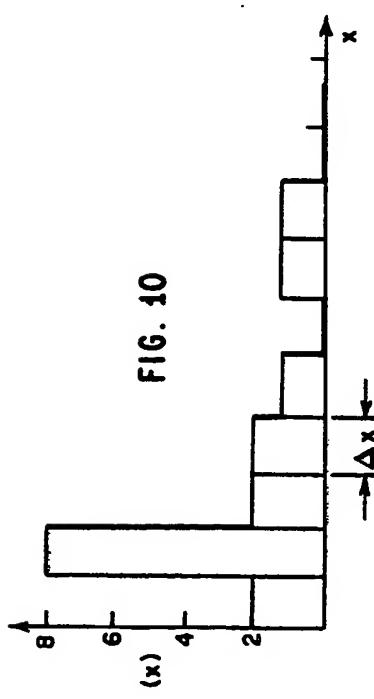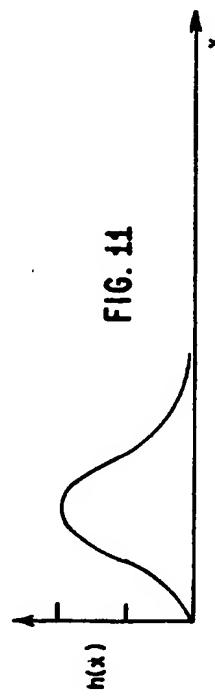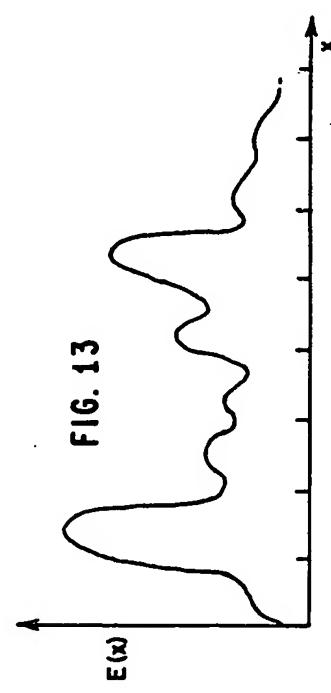
SPECIFICATION

Item identification tag for a rapid inventory data acquisition system

5   The present invention relates generally to inventory control and more particularly to automatic shelf inventory data systems.
    The availability of inventory technology coupled
10 with the sales downturn and increased operating costs of recent recessionary periods have combined to force retailers to meet competitors' aggressive pricing by using more stringent inventory control techniques. The hidden costs associated with excess inventory or
15 overstocking in the competitive retail industry are critically important. Large retailers estimate that the true costs of carrying inventory is on the order of 40% of the cost of the item per year. Moreover, the more inventory, the more manpower is required for inven-
20 tory control. Most importantly to the retail food and drug trade, however, overstocking results in inflexible pricing. In many stores, electronic cash registers at the checkout counters have been replaced by compute-rised point of sales terminals. Optical scanners and
25 bar codes on products, while posing other problems, allow flexible pricing and computerized real time inventory control and automated stock ordering. All in all, the various types of material requirement planning systems available today throughout the retail,
30 wholesale and manufacturing sectors have become an indispensable tool of cost control.
    Establishing precise control over retail inventory, however, requires more than reading bar codes at the checkout counter. In order to be purchased, products
35 have to not only be ordered but delivered, uncrated, unboxed, marked and moved from the stock room onto the shelves or peg racks in the retail store. Even overstocked items will fail to reach the checkout counter unless they are on the shelf.
40   Taking inventory for reordering or restocking of shelves is time consuming but essential, particularly where individual stores such as discount drug stores, stock thousands of shelf items. Shelf stock-taking should be fast and inexpensive to encourage daily
45 adjustments. However, today shelf inventory taken by visual inspection often requires manipulation of individual products hung eight deep on a peg rack. Bar codes are of little use on the shelf since they are usually hidden from view and in any event must be
50 individually scanned. Ironically, the optical techniques which are so efficient at the checkout counter are ill adapted for inventorying shelf goods.
    It is an object of the invention to provide means useful for an automatic inventory of shelf goods
55 without individual scanning or manipulation.
    According to a first aspect of the invention, an item identification tag comprises a plurality of coaxial, coplanar interleaved spiral conductive arms cut to lengths corresponding to specified frequencies. The
60 arms may be formed of etched conductive material on the surface of a flexible non-conductive substrate. In a preferred embodiment of the invention, the arms

consist of three pairs of juxtaposed arms, two of said pairs corresponding to a remotely transmitted pair of
65 frequencies, the third pair of arms corresponding to a third frequency which is an algebraic function of the pair of transmitted frequencies. The preferred tag is a circular printed circuit having three sets of two interleaved, coaxial, spiral conductive arms providing
70 three tuned circuits. Each pair of arms is cut to length corresponding to a frequency. The arm pairs are non-linearly, mutually capacitively and inductively coupled so that upon excitation at transmit frequen-cies, the tag emits a third frequency which is a function
75 (preferably the sum) of the first two frequencies. Such a tag may be made in the form of a tiny passive transponder small enough to be attached unobtru-sively to, for example, a lipstick.
    The tags may be used in a method of identifying and
80 determining the number of comingled stationary items by group distributed over an interrogation area. Thus, according to a second aspect of the invention there is provided an identification method for a plurality of intermingled groups of items, comprising
85 the steps of supplying a plurality of tags, each comprising at least two electronic circuit elements with adjustable electronic properties, assigning a unique set of said electronic properties to each group of items, dividing the tags up into sets corresponding
90 to the groups, adjusting the circuit elements of the tags in each set to achieve the electronic properties assigned to the corresponding group, affixing the tags in each set to the items in the corresponding group, and collectively testing the tags on an arbitrary
95 number of items to determine the membership of said groups.
    An inventory of individual products by stock keep-ing unit (SKU) may be obtained by collectively, remotely and automatically ascertaining the quantity
100 of products for a series of SKU's comingled on a given shopping aisle. A computerized transceiver, prefer-ably mounted on a wheeled cart, may be employed to sweep repeatedly through a set of transmit/receive frequencies to interrogate collectively all the products
105 belonging to specific SKU's arranged on a peg rack, for example. The data returned during interrogation at each SKU-specific frequency set is stored and com-bined mathematically by the computer to arrive at the total number of products in each of the interrogated
110 SKU's for a given stocking area in a drug store or supermarket, for example.
    The mobile transceiver preferably transmits at a pair of frequencies specific to a given SKU. Products of that SKU are equipped with tags which resonate at that
115 unique pair of frequencies and reradiate simul-taneously a third frequency to which the receiver portion of the transceiver is tuned. The amplitude of the third frequency detected by the receiver is a function of distance, receiver antenna pattern and the
120 number of tag products present on the shelf or peg rack of the particular SKU. As the transceiver moves down the aisle, the transceiver, preferably under software control, sweeps through the plurality of SKU specific transmit/receiver frequency sets. The fre-

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quencies may be derived from a master crystal
oscillator and tuned in phase-locked loop frequency
synthesizing circuits so that they will track precisely
the nominal SKU frequency sets.

5   The invention will now be described by way of
example with reference to the drawings in which:—
        Figure 1 is a pictorial perspective view of a
transceiver cart in a shopping aisle;
        Figure 2 is a schematic representation of the
10 transceiver interrogating a tagged product;
        Figure 3 is a plan view of a printed circuit tag;
        Figure 4 is an electrical schematic drawing repre-
senting an idealized equivalent circuit for the tag of
Figure 3;
15   Figure 5 is a block diagram of the transceiver;
        Figure 6 is a block diagram of one of the phase-
locked loops of the transceiver of Figure 5;
        Figure 7 is a block diagram of an alternative
embodiment of a portion of the transmitter circuitry;
20   Figure 8 is a block diagram of an alternative
embodiment of a portion of the reciever circuitry;
        Figure 9 is a schematic representation of a retail
pegboard rack from the front displaying products of a
specific SKU as dots.
25   Figure 10 is a histogram representing the quantity of
products in each incremental unit of distance along
the pegboard rack;
        Figure 11 is a graph showing the radiated signal
pattern as a function of displacement along the
30 pegboard rack;
        Figure 12 is a three-dimensional graph of the
radiated signal pattern as a function of displacement
along the pegboard rack and the product's elevation
above the floor; and
35   Figure 13 is a graph of the received energy from
plural tags as a function of displacement along the
pegboard rack.
        As shown in Figure 1, the interrogation system is
mounted on a cart 10 which can be wheeled down an
40 aisle in a retail store alongside a pegboard type
display rack 12 bearing products which are to be
inventoried. As shown in Figure 2, the transceiver 14
under the control of the microcomputer 16 transmits a
pair of frequencies F_1 and F_2 corresponding to a given
45 SKU. A packaged product 20 of the SKU being
interrogated is equipped with a specifically designed
printed circuit tag 22 which is resonant at the
transmitted frequencies and simultaneously reradi-
ates a third frequency signal F_3 which is picked up by
50 the antenna 18 and received in the transceiver 14. The
strength of the return at F_3 is measured and stored as
the cart 10 rolls along the display rack 12 and the
stored data is processed by an on-board programmed
microcomputer 16 to produce a numerical display 24
55 of the total number of units in the given SKU
corresponding to the frequency set F_1, F_2, and F_3. As
the cart is wheeled down the aisle, the microprocessor
controls the transmitter in the transceiver 14 to sweep
stepwise through all of the pertinent SKU's entered via
60 the keyboard 26 (Figure 1). The resulting numerical
quantities of products in each designated SKU are
printed out on command at the end of the aisle or
when the shelf inventory for the entire store is
completed. As an aid in processing the return signal
65 strength, the cart 10 is equipped with an odometer 30

which keeps track of displacement in the X direction
along the length of the peg rack and a sonar ranging
device 32 for keeping track of the distance of the cart
10 from the peg rack 12.

70   As shown in Figure 3, each product tag 22 comprises
six coaxial interleaved conductive arms 34, 36, 38, 40,
42 and 44 mounted on a flexible nonconductive
substrate 46. The arms themselves are made of etched
copper foil in the manner of a printed circuit. The inner
75 ends of the arms are connected to an array of six
spaced terminals, while the outer ends are trimmed to
length. The interwoven spiral arms are paired in such
a manner that there is a pair corresponding to F_1,
another pair corresponding to F_2, and a third pair
80 corresponding to F_3. Each pair is tuned to the
corresponding frequency by trimming the length of
the corresponding arms. The respective pairs are
nonlinearly mutually capacitively and inductively
coupled so that upon excitation at frequencies F_1 and
85 F_2, the tag emits a third frequency F_3 which is the sum
of the frequencies of F_1 and F_2. By assigning uniquely
cut tags to each SKU, all of the products on the shelf
can be differentiated by their frequency response. The
nonlinear capacitance effect is equivalent to a mild
90 piezoelectric effect and is designed to be essentially
nondirectional so that the response will be indepen-
dent of the products' attitude or orientation on the
shelf. The tag is intended in the preferred embodiment
to be about the size of a fingernail, approximately 1/4
95 to 3/8 of an inch in diameter and can be concealed in
the packaging itself since it is unnecessary to opticlally
scan the tag. Moreover, the tag can be bent or
wrapped, e.g. around a lipstick, without noticeable
effect on the function.

100   The equivalent circuit shown in Figure 4 illustrates
the nonlinear mutual coupling capacitors between the
spiral arms. The needed capacitance provided
through the proximity of the antenna elements in the
tag can be enhanced by the use of a solid sheet
105 conductor on the other side of the nonconductive
substrate 46. The coaxial resonator tag system is a
completely passive transponder in the sense that the
only energy which it consumes is that which it
receives from the transmitter on the cart.

110   The transceiver 14 consists of three major portions:
the transmitter, receiver and the microcomputer 16
which controls the system. In the transmitter, two
precise frequencies are generated under computer
command by phase-locked frequency synthesis. The
115 two frequencies are radiated to the SKU-specific tags
which act as radio frequency resonators and transpon-
ders. A particular tag will reradiate a frequency equal
to the sum of the transmitted frequencies if the
transmitted frequencies are the particular ones that
120 the tag is tuned to. If the tag is not tuned to the
transmitted frequencies, it will not return a signal. The
receiver section is instructed by the microcomputer to
"listen" for the sum frequency corresponding to the
two transmitted frequencies. The receiver is tuned by
125 means of another phase-locked synthesizer. The
computer sequences the synthesizers through each
selected set of frequencies.
        In the transceiver circuit of Figure 5, the IMHz output
of a crystal oscillator 50 is divided by 200 in counter
130 circuit 52. The resulting 5 KHz reference signal is fed in

parallel to three phase-locked loops 54, 56 and 58 corresponding to frequencies F_1, F_2 and F_3, respectively. Each phase-locked loop is implemented as shown in Figure 6. The 5 KHz reference signal forms one input
5 to a phase comparator 60 whose output is fed via a charge pump 62, phase compensation circuit 64 and amplifier 66 to the control input of a voltage controlled oscillator 68. The output of the oscillator 68 is a continuous wave signal which is fed via the power
10 amplifier 70 to coaxial output cable 72. The output of the voltage controlled oscillator 68 also forms the input to a feedback loop comprising buffer amplifier 74, a frequency halving circuit 76 and a divide by N circuit 78. The divided down output of the phase-
15 locked loop circuit forms the other input to the phase comparator 60. The value of N is determined by the microcomputer via a suitable interface chip 80 in order to select the specific value for frequency F_1, F_2 or F_3 associated with each SKU.
20   As shown in Figure 5, the output of two of the phase-locked loops are in nonoverlapping respective ranges 20-24 MHz and 25-29 MHz. These outputs are combined in a summation circuit 82 and amplitude modulated in modulator 84 by a 1,000 Hz square wave
25 derived from the 5 KHz reference signal via divider circuit 86. The amplitude modulated sum of signals F_1 and F_2 is fed via RF amplifier 87 and diplexer circuit 88 to antenna 18. The other side of the diplexer 88 feeds the received signal via another RF amplifier 89
30 through a 43-53 MHz bandpass filter 90 to a first mixer 92 which sums the received signal minus higher and lower frequency noise with the unmodulated F_3 output of phase-lock loop circuit 58 which serves as a local oscillator. Mixer 92 produces a 10.7 MHz output
35 signal which is amplified in IF amplifier 94 and passed to a second mixer 96 which mixes the first IF output with the output of a 10.245 MHz crystal oscillator 98. The output of mixer 96 is fed via a 455 KHz IF amplifier 100 to a synchronous demodulator 102 which demod-
40 ulates the received signal with the benefit of the 1,000 Hz modulation signal. The demodulated received signal is fed via analog-to-digital converter 104 (preferably 12-bit) back to the microcomputer 16 for processing.
45   A variation on the transmit circuit of Figure 5 is shown in Figure 7 in which the frequencies F_1 and F_2 are kept entirely separate. In experiments with a circuit constructed according to Figure 5, it was discovered that third order intermodulation distortion
50 of the output amplifier was high enough that simple filtering left the harmonic sum of F_1 and F_2 at a higher strength that the received reradiated signal from the tags. This problem is addressed in Figure 7 by providing separate modulators 110 and 112, RF
55 amplifiers 114 and 116, filters 118 and 120 and separate transmit antennas 122 and 124. Filters 118 and 120 should be carefully designed to eliminate mixing of the other frequency at the output of either amplifier 114 and 116.
60   An alternate design for a portion of the receiver is shown in Figure 8. A separate receive antenna 126 is used and after RF amplifier 89, the bandpass filter 90 is replaced by an varactor-tuned dual helical filter 128 which is controlled by the microcomputer via a
65 digital-to-analog converter 130. The filter 128 can be

approximately tuned to the desired received frequency to exclude unwanted interference.
     Antennas used in the designs of Figures 5, 7, and 8 are center-loaded, short, vertical dipole whip anten-
70 nas. Common practice is to make such antennas one-quarter wave length in length. However, at 30 MHz, this results in an impractically long antenna. Thus, the efficiency of the antenna is sacrificed to reduce its length. At higher frequencies more suitable
75 for use with the tag design of Figure 3, a more efficient antenna design will become practical. The vertical whip-type antenna, which exhibits linear polarization may be effectively replaced by a circular-polarized design to minimize variations in signal strength due to
80 tag orientation.
     With reference to Figure 9, assume that the peg-board rack has a number of products of the same SKU distributed as indicated by the dots. Displacement of the interrogation cart 10 (Figure 1) in the X direction is
85 indicated by the arrow marked X.
     The histogram in Figure 10 represents the exact quantity of products in any incremental slot delta X. This function is designated V(x) where V represents the specific number of products at any given location
90 along the x axis. A single radiating tag, for example, tag 22 in Figure 9 produces a radiated field with an intensity which exhibits and exponential distribution over the x axis as shown in the graph of Figure 11, H(x) representing the signal strength. Signal strength is
95 also, of course, a function of displacement in the vertical direction from the radiating tag 22, however, as shown in the graph of Figure 12, the slight variation can be safely ignored in most instances.
     If the cart 10 were rolled along direction x from right
100 to left in Figure 9, transmitting at the combination of frequencies F_1 and F_2 uniquely assigned to this particular SKU identified by the dots, the strength of the received signal would be distributed over the x axis as shown in the graph of E(x) in Figure 13.
105   Due to the overlap produced by the finite width of the radiated signals, the waveform in Figure 13 does not duplicate the histogram of Figure 10. Since the desired quantity, the inventory, consists of a sum and does not require reconstructing the exact shape of the
110 waveform as received, the microcomputer 16 is programmed to perform a numerical integration of the area under the curve of the graph of Figure 13.
     Assume that E(delta x_i) is proportional to m, where m is the total number of products in the ith delta x slot.
115 E, a function of x, is generally the convolution of the distribution function V(x) convolved with the radiated signal pattern function H(x) as given by the Equation 1.

$$E(x) = V(x) * H(x) \qquad (1)$$

120 Applying Fourier transforms to equation 1 results in Equation 2,

$$\epsilon(v) = V(v)H(v) \qquad (2)$$

125 which, when solved for the actual distribution function as a function of the frequency v, results in the following equation (Equation 3).

$$V(v) = \frac{\epsilon(v)}{H(v)} \qquad (3)$$

130

Thus, the actual distribution function is a ratio between the reconstructed pattern as measured and the transformed radiated signal pattern. The total number of products on the shelf T is (Equation 4).

5

$$T = \int V(x)dx \qquad (4)$$

Equation 4 can also be represented as the Fourier transform of the distribution function evaluated
10 where frequency equals 0.

$$T = V(v)|_{v=0} \qquad (5)$$

Substituting the ratio of Equation 3 and replacing the
15 Fourier transformed ratios with plain integrals of the untransformed distribution functions results in Equation 6.

20
$$V(v)|_{v=0} = \frac{\epsilon(v)|_{v=0}}{H(v)|_{v=0}} \qquad (6)$$

Since a complete reconstruction of the distribution pattern is unnecessary as only the total number of
25 products is desired, the Fourier transforms may be replaced by a simple running integral of the observed waveforms.

30
$$T = \frac{\int E(x)dx}{\int h(x)dx} \qquad (7)$$

Thus, the ratio shown in Equation 7 is sufficient to produce the total number of products on the shelf as measured during a walk-down of the shelf. Hence, a
35 simple numerical integration can be performed on the received data by the microcomputer 16 contained in the transceiver unit to produce the readout shown in Figure 2 of the quantity of a particular SKU on the shelf.
40 The numerator of Equation 7 is running numerical integration; the denominator is a measured system constant related to the signal pattern radiated by each tag. The running integration is best performed by a separate mathematical processor such as the Intel
45 8087 used as a coprocessor in conjunction with a main controller microprocessor such as the Intel 8086.
Since each product responds to a unique combination of frequencies F_1 and F_2, the microprocessor
50 must be fast enough to sweep through all possible combinations so that for a given minimum interproduct spacing delta x, each such delta x is sampled at least once for each SKU specific frequency set. The response at F_3 is processed by numerical integration
55 providing a running sum for each product on the rack.
The advantages of the above described automatic shelf inventory system are readily apparent. Radio frequency interrogation of comingled tagged products on a rack eliminates hand counting, visual
60 inspection of thousands of SKU's in a given retail store. The ability to establish precise control over the shelf inventory assures optimized inventory flow from the stockroom to the checkout counter. The retailer's profits are increased by eliminating inadver-
65 tent stock-out conditions. Moreover, the system is so

fast and potentially inexpensive that it can be used on a daily basis to track shelf inventory trends and make adjustments to inventory.
The tag can be mass-produced by printed circuit
70 techniques and can be made small enough to be invisibly incorporated in the packaging of even the smallest shelf items. The novel mobile interrogator enables an unskilled operator to completely inventory the shelf stock in a retail store without counting a
75 single SKU. Thus, human error is eliminated. The appropriate SKU numbers can be entered for a given aisle by preloading the computer memory with the SKU's which are normally stocked on a particular rack. Thus, the operator would only have to enter the
80 rack number. Alternatively, given sufficient computer speed and settling time for the transceiver, all of the store's SKU's could be interrogated on each walk-down of each rack. Because the frequencies are all derived from a single master crystal oscillator, any
85 drift would be experienced on all three frequencies simultaneously and the effect will be minimized.
The foregoing description of the presently preferred embodiments is intended to be illustrative and not restrictive. Many variations and modifications of
90 the overall system or individual components are possible, still employing the underlying principle of the invention, without departing from the scope of the invention as indicated by the appended claims.

CLAIMS
95 1. An item identification tag, comprising a plurality of coaxial, coplanar interleaved, spiral conductive arms cut to lengths corresponding to specified frequencies.
2. The tag of claim 1, further comprising a flexible,
100 nonconductive substrate, the conductive arms being formed of etched conductive material on the surface of the substrate.
3. The tag of claim 1, wherein the d tag is a printed circuit.
105 4. The tag of claim 1, wherein the arms consist of three pairs of juxtaposed arms, two of the pairs corresponding to a remotely transmitted pair of frequencies, the third pair of arms corresponding to a third frequency which is an algebraic function of the
110 pair of transmitted frequencies.
5. An identification method for a plurality of intermingled groups of items, comprising the steps of supplying a plurality of tags, each comprising at least two electronic circuit elements with adjustable
115 electronic properties,
assigning a unique set of said electronic properties to each group of items,
dividing the tags up into sets corresponding to the groups,
120 adjusting the circuit elements of the tags in each set to achieve the electronic properties to the corresponding group,
affixing the tags in each set to the items of the corresponding group, and
125 collectively testing the tags on an arbitrary number of items to determine the membership of said groups.
6. The method of claim 5, wherein said circuit elements have electronic properties determined by their length, the step of adjusting including adjusting
130 the length of the circuit elements.

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